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ANSYS-Based Numerical Model Validated through Laser Forming Experiments on Stainless Steel

Rizwan Sheikh, Jayant Khede, Rahul Chadhokar, Rahul Samre, Pradeep Singh Hada, Kapil Patodi, Manoj Raut

IPS Academy, Institute of Engineering & Science, Indore, M.P., India

ABSTRACT: This paper presents a statistical analysis of Structural Steel to study the special effects of process constraints (Laser Power, Scan Speed, Spot Diameters and Heat flow diameter). These process parameters are taken as input changeable and twisting angle or deformation considered as the output variable. An Ansys 18.1 licensed software tool is used for modelling and optimization of the laser bending method. The performance of the developed model and results is matched and checked with reference papers. All the process parameters are investigated and set up considerable effect on the bending angle. The effect of the beam diameter, scan speed and heat flow energy on bending angle also compare with research papers. The bending angle enhanced with an increase in beam diameter at stable heat energy but decreased with increase in heat energy at constant beam diameter. The bending angle is also affected by overlapping and gap between beam diameters.

KEYWORDS: Bending Angle, Laser power, Beam diameter, Scan Speed, Deformation, Heat, Ansys.

I. INTRODUCTION

Laser bending forming is a superior method in sheet metal bending forming in which a laser high-temperature source is involved to heat the metal job sheet and used to shape it. Laser forming do not make contact with objects of 2D bending, 3D shaping and precision arrangement on metal and non-metal apparatus. In this laser bending method a TGM (temperature gradient mechanics) across the thickness of the warmed zone generates different expansions across the width and thickness and thus a counter bending or twisting happens in the metal sheet plate.

In this process, plastic bending occurs in the section under a heated zone of laser beam. After the temperature of plate cold down, due to compressive plastic strains, the heated region minimizes their area and causes the plate deform in the form of bend in the reverse trend. This mechanism includes Temperature gradient mechanism (T G M), Buckling method (B M) and upsetting method (U M). Laser manufacturing included many applications like laser cutting, drilling on curved surfaces, heat treatment, welding of dissimilar metals etc.In laser bending process of sheet metals, heat flow provides on one face of the plate to melt and its effective temperature gradient developed, and this temperature gradient plays an important role in controlling the bending angle. Because of many intolerable problems in actual experimental problems with laser bending process, this simulation carried out which can provide very useful information taking position during the heat up and a cold succession of laser processing and this simulation reduces the investigational cost and time. This research is also essential as per increasing demand. In the present work, ANSYS 18.1 licensed software tool has been used for a model study.

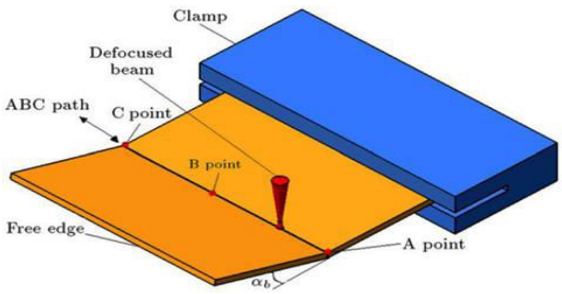

Fig. 01 Workpiece geometry

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Hennige et al (1997) carried out the investigational examinations on laser forming in the range of the temperature gradient method. They explained a satisfactory reproducibility of the bending angle and the bending radius for a wide range of bending procedures. In order to realize a precise bending angle a closed loop method was constructed, making exactness bending to within correctness of + 0.2" probable [4].

Cheng and Yao (2001) investigated experimentally and numerically the outcome of enforced cooling on single-scan laser forming procedure. Effects of Cooling under various conditions, including variable laser power, scanning speed, nozzle offset, and cooling air pressure, are investigated. Special effects of Cooling on micro formation transform and other mechanical assets, including strength, ductility, and hardness were also inspected. The centre of attention was to investigate the cooling effect on the bending mechanism, including challenging effects on temperature and flow stress. A commercially available software ABAQUS was deployed to resolve the heat transmit and structural dilemma [5].

Maji et al (2013) did a relative study of continuous and pulsed laser bending and conclude that the bending angle depends on the input variable. According to them, twisting angle improved with the rise of laser power and pulse duration and reduce with the rise of scan speed and spot diameter [1].

Sivankutty et al (2014) have used Analysis of Variance (ANOVA) to establish the considerations which affect the bending angle the mainly. They applied laser heat source all the way through a straight path in sheet metal and used AISI 304 SS material properties and created FE model and experiments [2].

Lambiase et al (2015) conducted a series of investigational tests on this sheets made of AISI 304 SS and found the variation of the bending angle by multi-pass laser and modelled an Artificial Neural Network for achieving bend angle per pass [6].

Cruz et al (2015) have proposed and evaluated a 2D model, which is able to take into account the effect of the moving point heat source. They have also concluded that the effects of all three dimensions and the heat source movement are relevant for the ultimate precision of the simulation results, and to obtain the correct tendencies of the effect of changes of some of the parameters on the process results. And these results also demonstrate that some relevant thermal and stress data can be obtained using simplified models at a considerably lower computational cost [7].

Nath et al (2016) studied the thermal effects due to heat input into the work-piece and analyzed the temperature distribution, thermal gradient distribution and variation of thermal properties with time. They worked by using thermo-mechanical elasto-plastic simulation on ANSYS software by using work-piece of D36 shipbuilding steel sheet [3].

The main issue is that very less work has been completed in this field compared to experiments; however, the process has been shown to have a great deal of potential. In order to compete directly with forming techniques though, laser bending process must be proven to be reliable, repeatable, cost-effective and flexible. It is easily design, analyze and predictable in the laser bending forming that offers the greatest benefits with theoretical knowledge, in that a change to required part geometry could be implemented easily.

From the above literature survey, it clear that there are many grey areas for the industrial adaptability of the LBF and these needs to be addressed. Hence, it is proposed to Identify the response variables related to the changes in geometry and material microstructure that characterize the quality of a laser-formed bend. The change in geometry is simply a change in the angle across the laser scan line between both undistorted sides of a workpiece.

Identify the laser forming process variables that influence the changes in geometry and material microstructure of workpiece and their degree of controllability.

II. NUMERICAL SIMULATION MODELLING PROCESS

The model created for the calculation of the results in form of bending angle or deformation is based on the postulations:

1. During heating time, metal sheet goes under plastic disfigurement [9].
2. After heating in the cooling phase, the top layer of the plate contracts and the base surface of the plate expand as the two surfaces achieve the normal temperature [9].
3. In cooling phase, the correspondent mechanical stresses generate strains. If a plate temperature goes down by ΔT temperature, its quantity to applying $\alpha_{th} E \Delta T$ compressive stress to a surface. A parallel similarity can be given

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when the plate warm-up [9].

4. The corresponding mechanical stresses and strains cause elastoplastic deformation and the output results bend angle can be achieved by a usual theory of elastoplastic bending expressed in the books, e.g., Chakrabarty (2006) [9].

III. NUMERICAL SIMULATION

The laser forming processing of Structural Steel is pretended with ANSYS18.1. All the boundary conditions are depend on the temperature, which has been given by Papazoglou(1981). Some statements are made as follows [10]:

1. The material of the metallic sheet is isotropic and consistent [10].
2. The primary stress status of sheet metal is free [10].
3. The properties of the sheet are also temperature dependent. The properties include thermal expansion (α), density, conductivity (k), yield stress (σ), specific heat and Young's modulus (E) [10].
4. Radiation is unseen in the heat transition, and the simulations have confirmed that the radiation effect on the bending angle is very minute [10].
5. Do not take into account the heat generated by the phase transition because the maximum temperature is lower than the melting temperature [10].
6. According to Von-Mises yield criterion, the solidifying and the plastic deformation rule are engaged [10].
7. The bending deformation is very small and the weight of the plate is not considered [10].

The laser shaping procedure is a mind-blowing process that includes numerous marvels, and an extensive number of factors and properties that impact the procedure straightforwardly or by implication. It incorporates the optics to characterize the beam shape and irradiation density, the assimilation procedure and the heat conduction into the material, the thermo-elastoplastic distortion of the material, the microstructural advancement of the material. These marvels are coupled, despite the fact that a portion of the couplings and interaction are less strong than others [11].

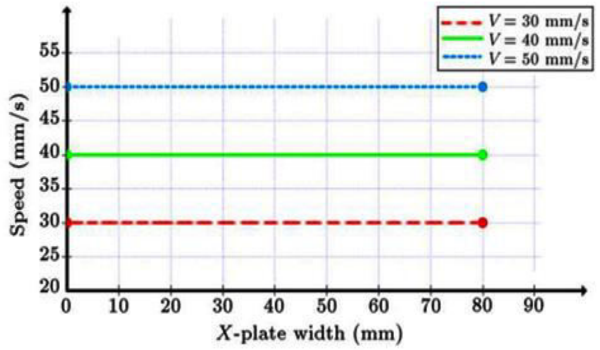

Fig. 02 Scan speed Fixed pattern (30, 40 and 50 mm/s) [11].

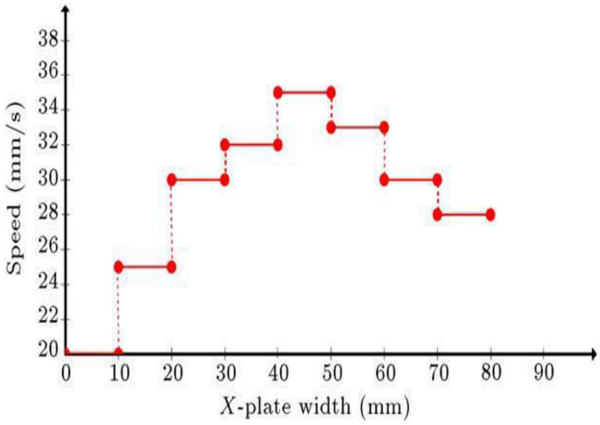

Fig. 03 Scan speed Step pattern [11].

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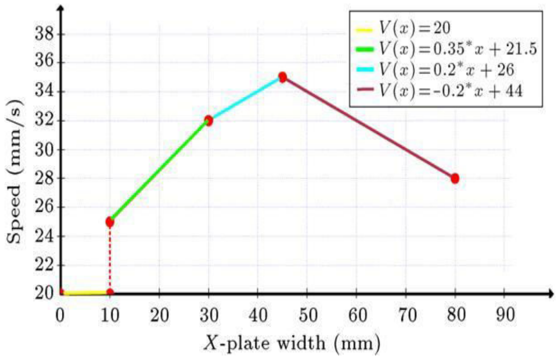

Fig. 04 Scan speed Inclined linear pattern [11].

The temperature distribution T in the material is solved from the heat diffusion equation

$$\rho c \frac{\partial T}{\partial t} + \nabla . q = Q$$

where ρ is material density, c is the specific heat of the material, T temperature, q heat flux, and Q is the internal, domain heat source rate.

Usually, heat losses are overlooked to the environment, as they are little as contrasted and the size of the heat source. Notwithstanding, it tends not out of the ordinary that their impact is significant amid the cooling stage, so it has done via convection and this condition was imposed as the following equation

$$q_c = h_f \, (T - T_0)$$

And hear transfer was obtained via radiation

$$q_r = \varepsilon_r \sigma_b \, (T^4 - T_\infty^4)$$

where hf is the convection coefficient (10 W/m2 0C), T0= 200C is the room temperature, T is the surface plate temperature σb is the constant of Stefan–Boltzmann (5.68 x 10-8 W/m2K4), and εr= 0.4 is the radiative emission coefficient [11].

IV. EVALUATION OF SIMPLIFIED MODELS

Keeping in mind the end goal to measure and evaluate, the impact of every disentanglement on the outcomes acquired different improved models is proposed and examined. All models are contrasted with the outcomes got in an entire 3D transient model.

Table 1: Value of Evaluation parameters used in different patterns [11].

S. No.	Laser conditions			Sheet Metal parameters			
	Power (W)	Irradiation Dia. (mm)	Scan pattern type Velocity (V)	Width in mm	Thickness in mm	Beam position in mm	Length in mm
1	1000	5	Constant= 30 mm/s	80	2	40	80
2	1000	5	Constant= 40 mm/s	80	2	40	80
3	1000	5	Constant= 50 mm/s	80	2	40	80
4	1000	5	Step	80	2	40	80
5	1000	5	Inclined linear	80	2	40	80

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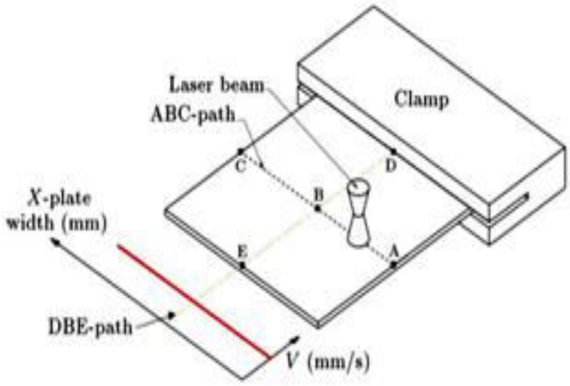

Fig. 5: Scan Patterns

The laser forming process examined includes the heating through a straight line of a 1.0584 (D36) steel sheet. The measurements of the geometry have appeared in Fig. 1. To dissect the contextual investigation appeared in Fig. 1, four instances of disentangled investigation are characterized as shown in Fig. 2. Each contextual investigation expects to streamline the multifaceted nature of the transient 3D issue in various courses, either by constraining the measurement of a 2D issue or by displaying the issue without displacement of the heat source.

The heat source must be altered to satisfy the prerequisites in every one of the improved cases (Fig. 2), with the end goal that the heat input is tantamount. The laser control utilized for this situation is 1.5 kW at a speed of 5 mm/s; consequently, the time amid which heat is applied over the 150 mm line is 30 s, bringing about an aggregate heat contribution of 45 kJ (an extra 3.2 s is to be added for the heat source to enter and exit the domain limits). For cases 1, 2, and 3 the heat source development is excluded unequivocally in the model, so the time of heat supply is decreased to the laser–material interaction time: the time taken in which the laser spot moves over a material point, which is 3.2 s for the 16 mm spot utilized, bringing about substantially higher power esteems. At long last, for cases 2 and 4 the heat source is a volume source in the surface space, though in cases 1 and 3 the heat source is applied as a heat flux boundary condition.
Cases 1–4 are all calculated without ambient heat losses. So as to evaluate the impact of the encompassing heat losses, case 5 is included with indistinguishable conditions as case 3 aside from the consideration of convection and radiation conditions [11].

V. METHODOLOGY

This research is studied based on a transient thermal-structural analysis by using the Finite Element Method (FEM). The sequentially coupled thermal and mechanical analysis is carried out by using Gaussian distributed moving heat flux over the Structural Steel sheets of size 80×80×2 mm3 [11].

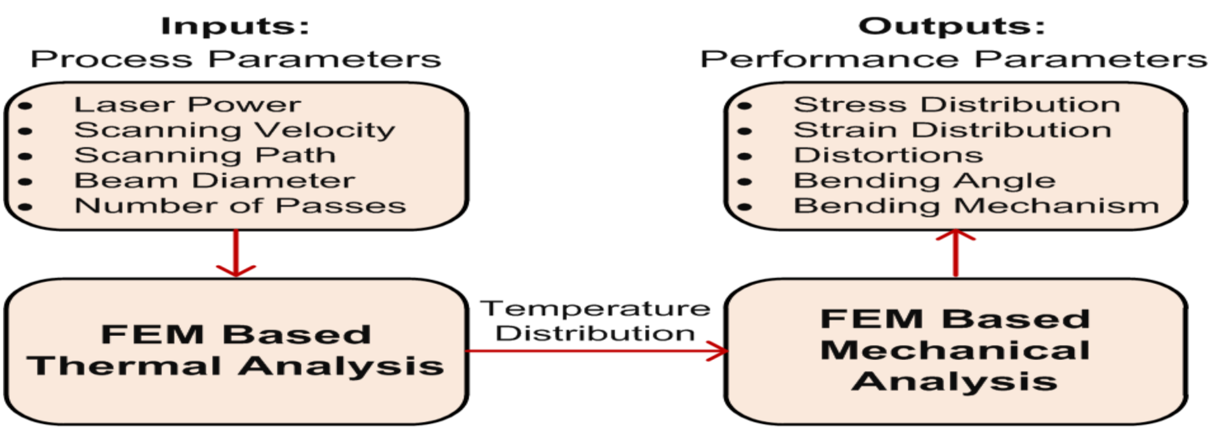

Fig. 6: Modelling on ANSYS 18.1

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VI. RESULTS

1STCASE

The laser shaping procedure was displayed by utilizing the FEM, as indicated by the points of interest given the first line in Table 1 and Figures 5. At that point, the after-effects of temperature 199.380C were evaluated by Ansys 18.1. In first case, the laser heat providing time value was 2.66 s.

This deformation (Figure 7) occurs because of the thermal expansion and contraction caused by heat radiation. Therefore, initial counter bending and then straight bending occur.

The time taken in this process is specified by the change in temperature
= 1.33 − 1.273 = 0.057 s.

Regarding Fig.1, toward the start of the task, the metallic sheet is in a straight line, in any case, toward the finish of the activity, its shape changed. This undesirable buckling is called longitudinal bending, which happens in the laser forming process toward the finished task. As indicated by the outcomes exhibited in Figure 7, longitudinal deformation at the end is most extreme and, in the start, is least. This occurs, in light of the fact that the most extreme heat generation happens behind the laser beam, and, hence, at greater temperature, a more prominent sheet metal displacement happens toward the end of the path.

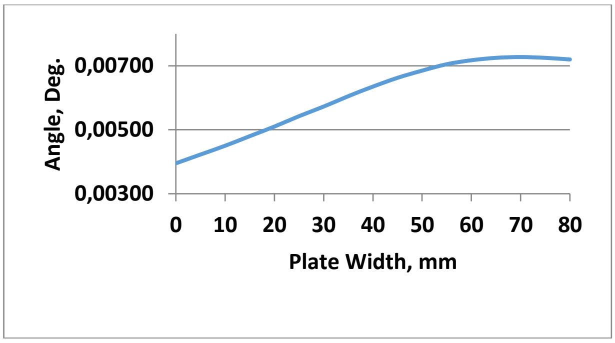

Fig. 7: Bending angle more about along the free edge of sheet related to case 1.

2NDCASE

As indicated by the second column points in Table1 and Fig5, the modelling was executed by FEM. The time taken for heating was 2s. For this situation, longitudinal deformation and bending angle very along the length of a free edge of the sheet metal. The twisting angle esteems diminished contrasted with case 1. In the second type case (V = 40mm/s), the finite element outcomes are nearer to the first case outcome. In this way, as the rise in scan speed, more exact outcomes can be attained by FEM.

In the second case, an increase in the scan speed, the bending angle at position A and C is reduced (Fig8).

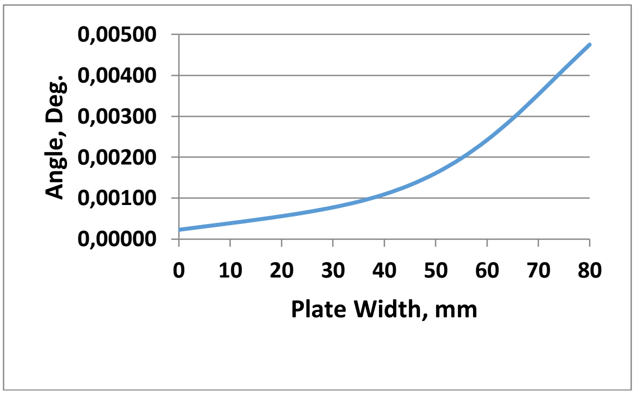

Fig. 8: Bending angle longitudinally of sheet metal related to the second case.

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3RD CASE

In case3, as shown by elements of the column3 in Table no.1 and Fig no. 5, the simulation was executed by FEM. The time of irradiation was 1.6s. As pointed out by the higher irradiating speed, longitudinal deformation diminished compared with the first and second cases.

In the third point, due to raising the speed of scanning 50 mm/s, the angle due to distortion is increased match with the previous cases.

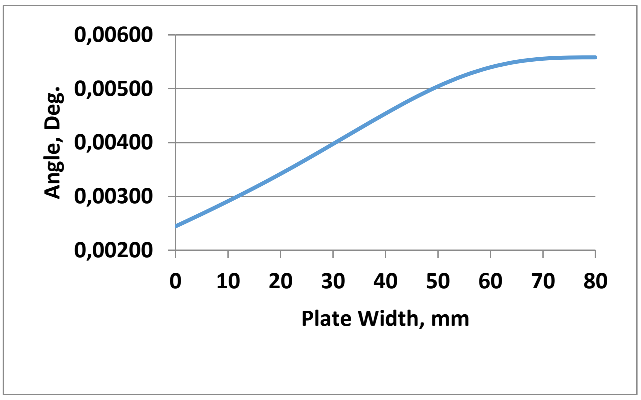

Fig. 9: Bending angle or distortion of sheet metal related to the third case.

4TH CASE

Here, the progression check design was chosen as a variable parameter. For this situation, the point in time taken to shift the laser beam along the path of A-B-C line is traced in around 8 stages, which are as follows:

Time = 0.25s− 0.7 s− 1.066s− 1.389 s− 1.688 s− 1.983 s− 2.301 s− 2.64 s

These period are same at which the centre directions of laser beam achieves in each step of Fig10.

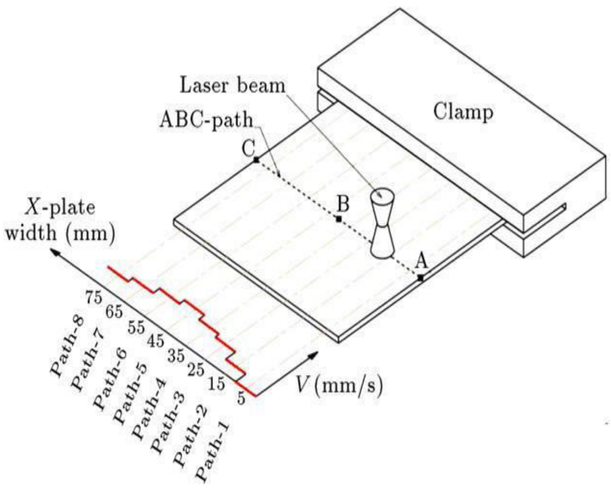

Fig.10: Scan step patterns Model related to case no. 4.

Here in the 4th case the deviation in the bending angle is exposed in Fig.11. The maximum value is at 30-40 mm from the origin, and two values which are minimum at the starting and closing stages of the curve (Fig11).
In any case, the state of the outline is more like parabola than in past cases.

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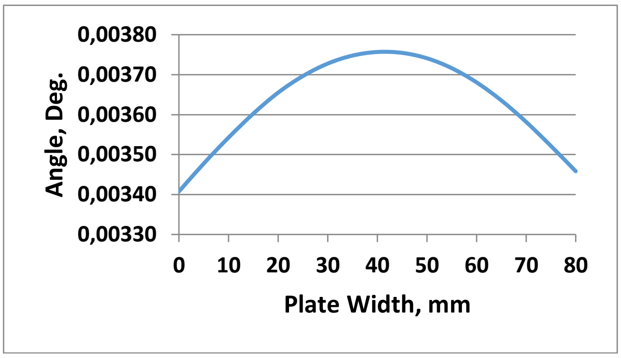

Fig. 11: Along the free edge bending angle of sheet metal workpiece related to case no. 4.

5^TH^CASE

Here, In the table1 inclined linear velocity of scanning as a inconsistent parameter was selected. The time taken in this pattern to move the laser beam along the direction of path ABC is recorded in 4th steps are as follows:

$$\text{Time} = 0.7 - 0.2 - 1.485 - 2.164 \text{ in sec}$$

This duration of scan pattern are equivalent to the time taken (Fig12) in which the laser beam achieves the centre point directions of each step. Here we determine the temperature distinction because of an scan speed increment in between two scopes of 0mm< x < 10mm and 10mm< x < 30 mm.

In the scan pattern of linear inclined, the value of strain distribution the length of path 2 is a smaller amount than that of the other three paths, owing to a decrease in heat temperature and the provide a quick inclination of speed variation. The deformation curve acquired is a parabola. Be that as it may, at distance from free end 30 mm and the evaluation of deformation has its most extreme value, and, at a position of point A and C, the bend is near zero in Fig 13.

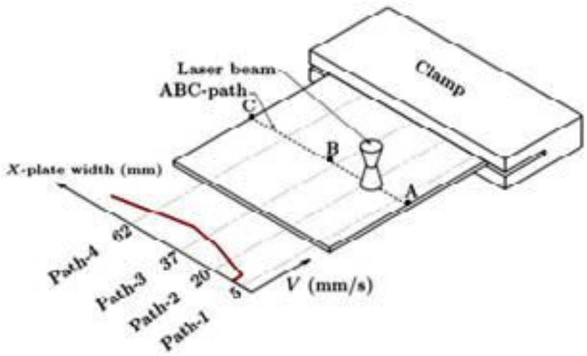

Figure 12: Scan inclined linear velocity patterns Model related to case no. 5.

The FEM overrated the evaluation of longitudinal bending deformation compared to the previously estimated method. In this analysis, the pattern for the bend of the edge impact is very not the same as past cases, with the goal that the most extreme bending angle happens at the point A. The angle position has been diminished contrasted with previous cases. This reduction in metal was more intense in investigational results as in fig 13. In the above cases, the outline state is more like full parabola curve than in above cases fig13.

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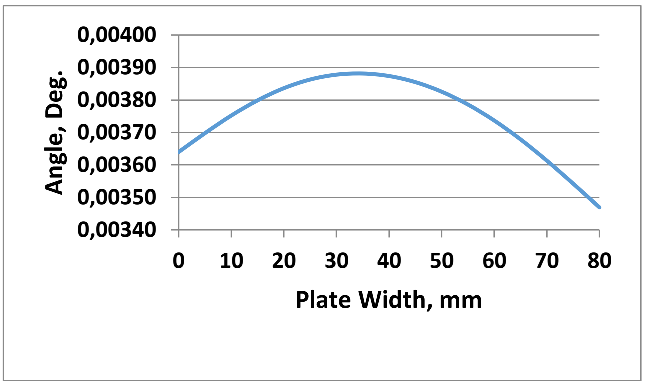

Fig. 13: Longitudinally Bending angle of sheet metal (case no. 5).

VII. CONCLUSION

Temperature gradient along thickness heading was in charge of the worksheet bending.
Laser Power, irradiation speed and beam dimensions influence the angle made in a sheet. Bend angle was diminished with increment in beam diameter while it was first increased and after that diminished with laser power.

The materials having high heat conductivity ought to be prepared at higher scanning speeds with the goal that higher temperature slope and subsequently higher bend angle can be accomplished.

The numerous laser beam illumination should be possible to get the larger bending angle and the angle in sheet per pass was more for a higher number of laser bar scanning.

In curvilinear laser bending procedure, worksheet was bend outer surface of the scanning way curvature. The angle of bend in sheet was more for higher scanning path curvature.

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